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Emergency Closure of Uncontrolled Flow at Locks and Dams

Stephen T. Maynord and Richard L. Stockstill

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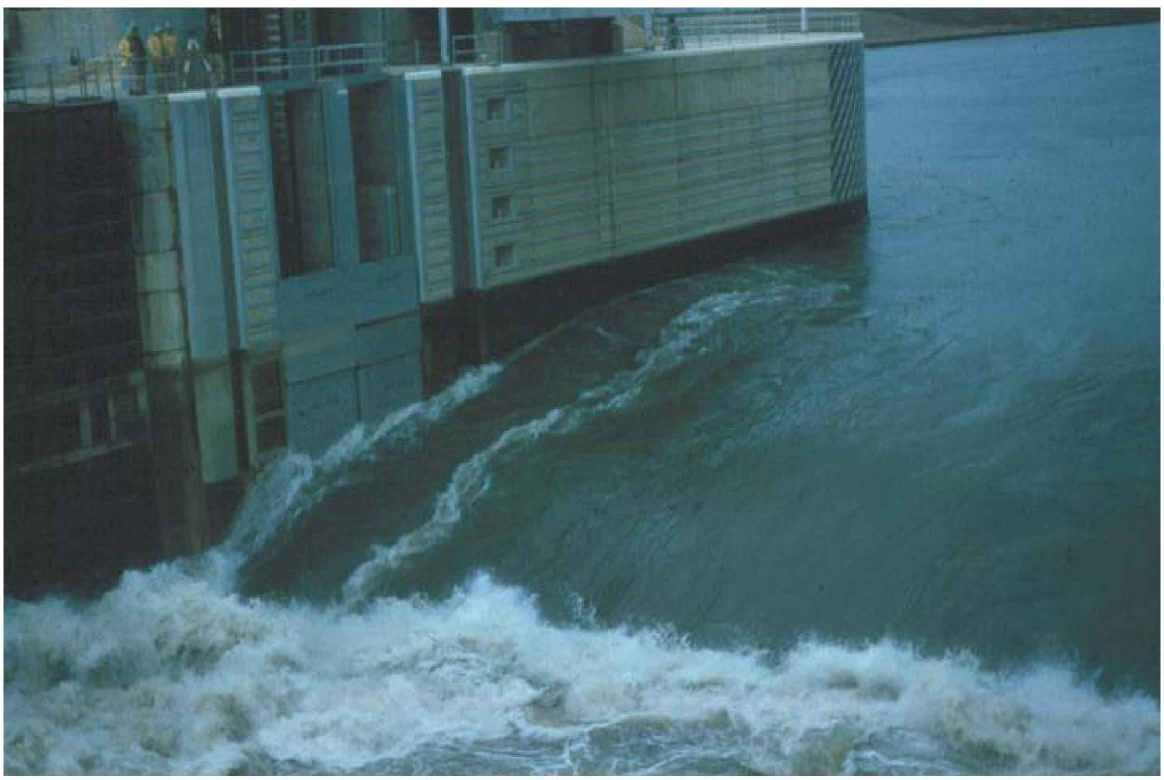

Emergency Closure of Uncontrolled Flow at Locks and Dam

Stephen T. Maynord and Richard L. Stockstill

Coastal and Hydraulics Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

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Washington, DC 20314-1000

Abstract

This report presents a review of emergency closure devices for locks and dams. It focuses on the hydraulic aspects of emergency closure using either a gate placed as a single unit or one placed as a series of individual sections. This report also examines guidance, past field experience, and model investigations of placing emergency closure gates in flowing water. A concept for an alternative means to stop water flowing through an open spillway bay is also proposed.

Contents

Figures

Figures

Preface

The investigation reported herein was sponsored by the Navigation Systems Research Program (NSRP). This work was conducted in the Coastal and Hydraulics Laboratory (CHL) of the U.S. Army Engineer Research and Development Center (ERDC) during the period of July 2011 to February 2012 as part of the NSRP work unit “Hydraulic Design Guidance for Locks and Dams.”

This research was conducted under the general direction of Dr. William D. Martin, Director of the CHL; Jose E. Sanchez, Deputy Director, CHL; Dr. Rose Kress, Chief of the Navigation Division, CHL; and Dr. Richard B. Styles, Chief of the Navigation Branch, CHL.

This investigation and subsequent report was completed by Dr. Stephen T. Maynord and Dr. Richard L. Stockstill of the Navigation Branch, CHL. The report was peer reviewed by Dr. John E. Hite, Jr., Navigation Branch, CHL. Acknowledgments are made to Charles E. Wiggins, Navigation Systems Research Program Manager and Jeff Lillycrop, Technical Director for Navigation, ERDC.

At the time of this report, COL Kevin J. Wilson was Commander and Executive Director of ERDC. Dr. Jeffery P. Holland was Director.

Unit Conversion Factors

Multiply	By	To Obtain
feet	0.3048	meters
kip	4448.221	Newtons
pound (force)	4.44822	Newtons
ton	8896.44	Newtons

1 Introduction

1.1 Background

The U.S. Army Corps of Engineers (USACE) and other agencies have experienced accidents, misoperation, and structural failures at hydraulic structures resulting in uncontrolled release of flow through spillway gate bays, lock chambers, and other hydraulic control structures. Hite (2008) documented recent examples of accidents where barges struck the dam, which in some cases, caused loss of pool. Freckleton et al. (2011), point out that “Emergencies resulting in uncontrolled flow through spillway gates often lead to millions of dollars lost to repairs, lack of dam productivity, property damages, and risks to public health and safety.” The engineering manual EM 1110-2-2607, “Planning and Design of Navigation Dams” (Headquarters, USACE 1995), states that determining whether emergency closure structures are necessary depends on the consequences of loss of pool, economic losses to shipping interests, flood damage and danger to people downstream, and damage to channel banks due to rapid drawdown.

Stop logs are usually wooden beams and bulkheads are typically steel structures; however the term bulkhead and stop logs are used interchangeably (Headquarters, USACE 1987). This technical report uses the term “emergency closure gate” to identify a closure device designed to be placed rapidly in flowing water under a head differential. Lewin (1995) lists characteristics of emergency closure gates including:

- Ability to close against flow;
- Has rollers not normally found on maintenance gates, which are not designed to close against flow;
- Can be in one section or segmented and assembled into one unit before lowering;
- Cannot be placed as individual units in flowing water because they are subject to vibration from combined flow over and under the section;
- Should only be handled by a rail mounted gantry crane because downpull forces can topple a mobile crane;
- Can perform the function of a maintenance gate if needed.

Although Lewin (1995) suggests that individual sections cannot be placed one at a time, model studies and a prototype test have shown that this method of deployment can be used successfully.

Hite (2008) provided different concept designs for emergency closure and gathered input from USACE field personnel describing the features necessary for a functional emergency closure system. One of the alternatives identified was a segmental bulkhead unit. Field personnel identified the following attributes of the segmental bulkhead units (Hite 2008):

- Are adaptable (adjustable length) for 110-ft- wide lock chamber or 100-ft-wide dam gate bay;
- Can be transported over highway using flatbed trailer;
- Should be segmental;
- Do not require specialized equipment to deploy.

The issue of bulkhead storage must be resolved. Generally, there is not sufficient clearance to store (dog) at the top of the bulkhead slot on spillways. Although, one unit may be placed in the slot while the remaining units for each spillway bay are placed on the deck.

1.2 Closure of navigation structures

The prevention of loss of upper pool requires the capabilities to employ emergency closure of spillway gate bays and lock chambers. The emergency closure device is used to close the lock chamber or spillway gate bay during emergencies to prevent the l0ss of pool. Therefore, the device must be capable of closing through flowing water against a maximum head differential of normal upper pool and low tailwater. Emergency closure of a spillway gate bay may be required if the gate is critically damaged or the hoisting mechanism is inoperable with the gate in a raised position. A typical spillway emergency bulkhead configuration is illustrated in Figure 1. Emergency closure of locks will be required in the event that an upper lock gate is critically damaged at a time when the lower lock gates are in an open position. Emergency closing procedure of a lock is shown in Figure 2.

Engineering manual EM 1110-2-2602, Planning and Design of Navigation Locks (Headquarters, USACE 1995), provides a Case History regarding an accident that occurred at the Markland Lock and Dam in 1967. Loose barges floated into the dam, some sank in the dam's gate bays, some wrapped around piers, thus preventing the closure of tainter gates. The resulting loss

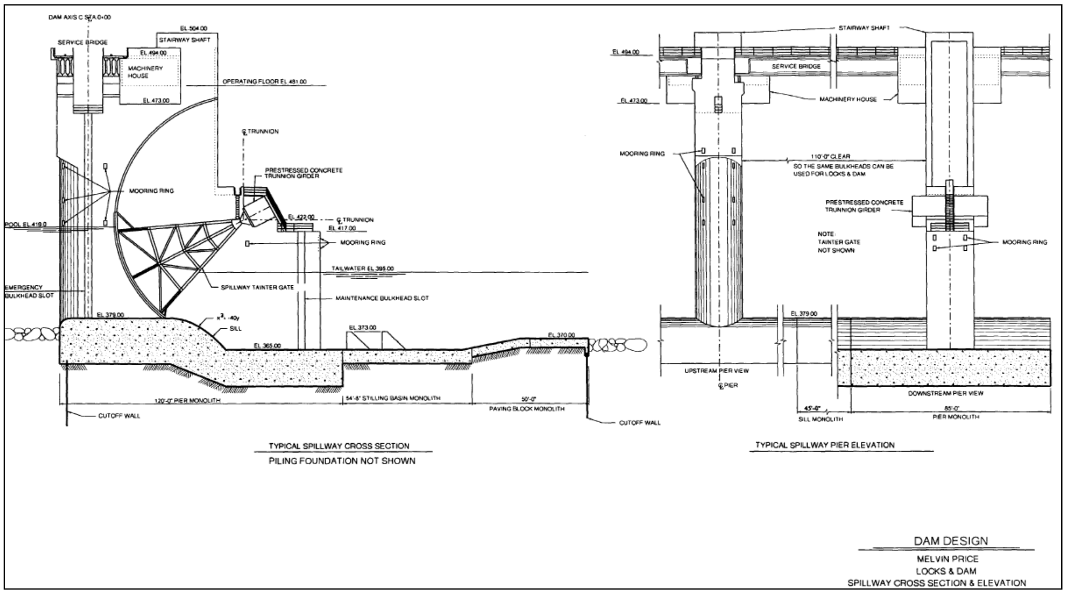

Figure 1. Typical spillway emergency bulkhead configuration.

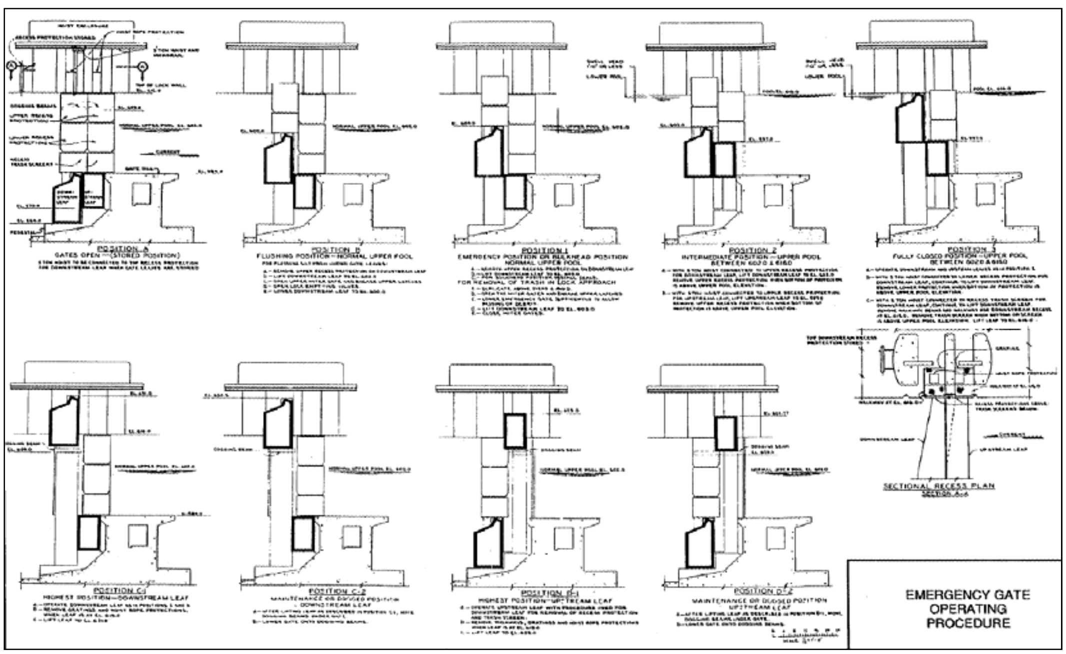

Figure 2. Typical lock emergency gate operating procedure.

of pool caused major damage to harbors, stranded boats, sloughed highway embankments, water intakes, and sewer outfalls (Headquarters 1995). A list of recommendations is given in EM 1110-2-2602. The point is made that training programs for lock and dam operation personnel should be conducted to prepare them for the decisions that must be made during emergency situations. It also recommends that seminars should be held periodically to review plans for recovery operations.

1.3 Purpose

The purpose of this report is to provide engineers with a concise description of the hydraulic aspects of emergency closure. The closure devices are either a gate placed as a single unit or one placed as a series of individual sections. This report also examines guidance, past field experience, and model investigations of placing emergency closure gates in flowing water. A concept for an alternative means to stop water flowing through an open spillway bay is also proposed.

2 USACE guidance

Engineering manual EM 1110-2-2607, Planning and Design of Navigation Dams (Headquarters, USACE 1995), states that the USACE has primarily used stacked bulkheads and vertical-lift gates for emergency closures. “The stacked bulkhead arrangement has proven to be the most dependable and reliable for emergency closure purposes.” The bulkheads have end rollers and are usually of the open truss design with skin plate on the upstream side.

EM 1110-2-2607 notes that several cases of barge collisions have resulted in barges becoming lodged at the bulkhead gate location and have precluded installation of emergency closure gates. The “Lessons Learned - Case Histories” in Appendix C of EM 1110-2-2607 documents the seriousness of barges blocking and sinking upstream of navigation dams.

The manual states “Past experience and model testing by WES have shown that bulkheads cannot be lowered safely one at a time in flowing water. Therefore, the stacked bulkhead system was developed so that the flowing water never goes over the top of the bulkheads.” EM 1110-2-2607 also states that placement of emergency closure bulkheads can be accomplished from a floating plant, which is contrary to Lewin’s (1995) recommendation that a rail mounted gantry crane be used.

EM 1110-2-1604, Hydraulic Design of Locks (Headquarters, USACE 2006), states that the most common type of emergency closure gate is a bulkhead consisting of one or more sections. The bulkhead uses a watertight skin plate on the upstream side and includes seals and roller assemblies. The vertical height of the bulkhead varies from 3 to 12 ft. EM 1110-2-1604 also notes that most designs do not permit combined flow over and under the gates. The manual describes the placement procedure in which the gates are “dogged” to hold them in position. This is the placement procedure used at Belleville Locks and Dam, which is discussed later in this report.

EM 1110-2-2703, Lock Gates and Operating Equipment (Headquarters, USACE 1994), provides details and design loadings for various emergency closure gates. An overview of design load information in EM 110-2-2703 is that:

- Hydrodynamic forces on emergency bulkheads can result in uplift and downpull depending on the design;
- Lowering bulkheads in flowing water requires that the uplift force is less than the submerged weight of the bulkhead;
- Design of hoisting machinery requires knowledge of the magnitude of hydraulic downpull.

3 Emergency closure gates lowered as individual units

3.1 Generalized spillway model tests

Eschler (1958) completed a generalized study of the placement of bulkhead sections. The study used a 1:51-scale model of a dam having spillway bays that were 23 m (75.4 ft) wide. Emergency closure of the structure used five 2.8-m (9.2-ft)-high bulkhead sections with rollers that were placed individually with flow over and under the section. The sections were constructed as an open truss with a skin plate on the upstream side. A vertical gate downstream of the emergency bulkheads was used to vary flow during deployment of the bulkhead sections. One limitation of the study was that loads were measured with a beam and weight system that only provided average loads without time variation information. The cross section of the bulkhead is shown in Figure 3. Figure 4 is a plot of the loads during deployment of the first section for the largest flows tested by Eschler (1958). The plot also provides loads generated during deployment of the second section with the first section already seated. Negative vertical force on the horizontal axis is uplift and positive is downpull. The submerged weight of the gate has been subtracted from the vertical force. For example, during placement of the first section, a downpull force of about 88 tons occurs when the bottom of the section is between 5 and 8 m (16 and 26 ft) above the sill and the downstream gate is open 10 m (33 ft) or more. Figure 4 also shows that a smaller distance between the bulkhead bottom and the sill

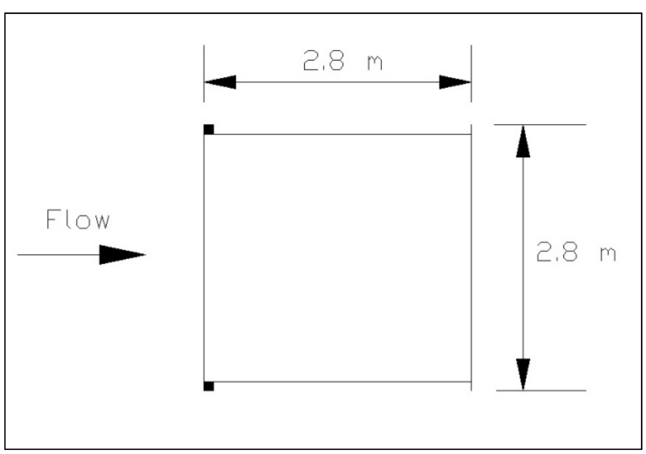

Figure 3. Eschler (1958) emergency closure gate.

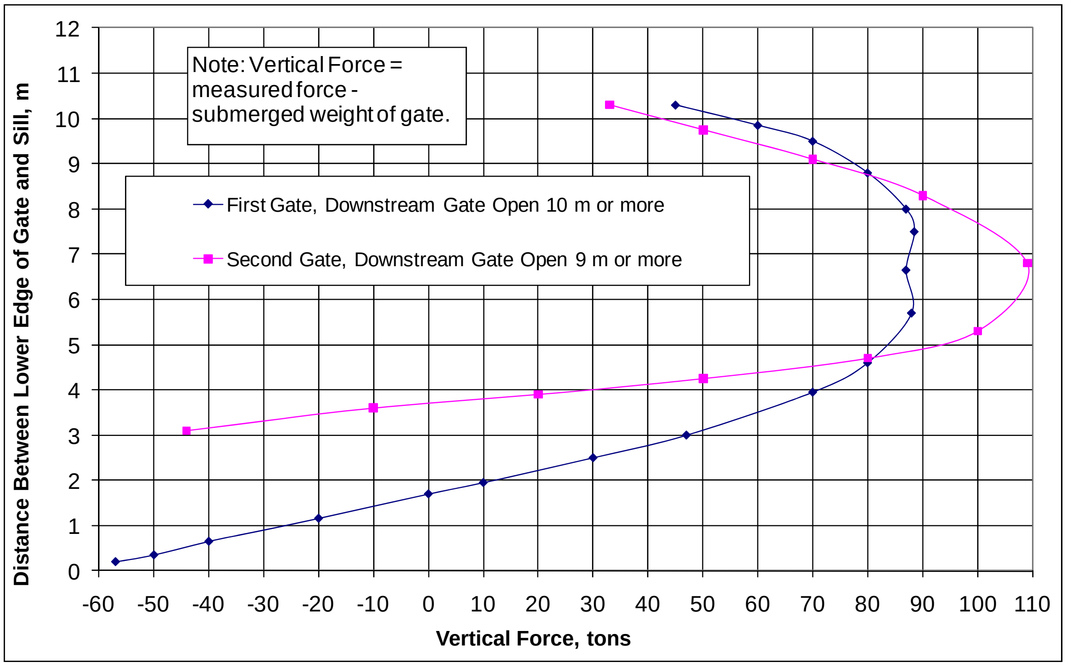

Figure 4. Eschler (1958) results for deployment of individual closure gate. For second gate deployment, the first gate is already seated.

results in an uplift which prevents the gate from being seated. Additional tests were conducted with a girder type design having solid plates rather than the open truss design. Vertical forces with the girder design were always larger than the open truss design.

3.2 New Cumberland Locks model tests

Melsheimer and Murphy (1961) conducted tests of single bulkhead sections with a lifting beam, deployed under flowing water conditions. The bulkheads were an open truss design with skin plate on the upstream side. Details of the bulkhead are shown in Figure 5. The individual bulkhead gates were stable throughout the deployment with a normal upper pool elevation and heads as large as 22.5 ft. However, the individual section experienced large uplift and significant fluctuations when the upper pool was higher than normal and the head was 30 ft.

3.3 Kainji Dam model-prototype correlation

Model and prototype tests of emergency closure gates for the Kainji Dam in Nigeria were reported by Coxon et al. (1973). The 16 emergency gates in each of the 8 spillway bays were placed individually in flowing water with flow both over and under each gate. The laboratory experiments used a 1:20-scale model of emergency closure gates that were 22.5 ft long by 2.6 ft

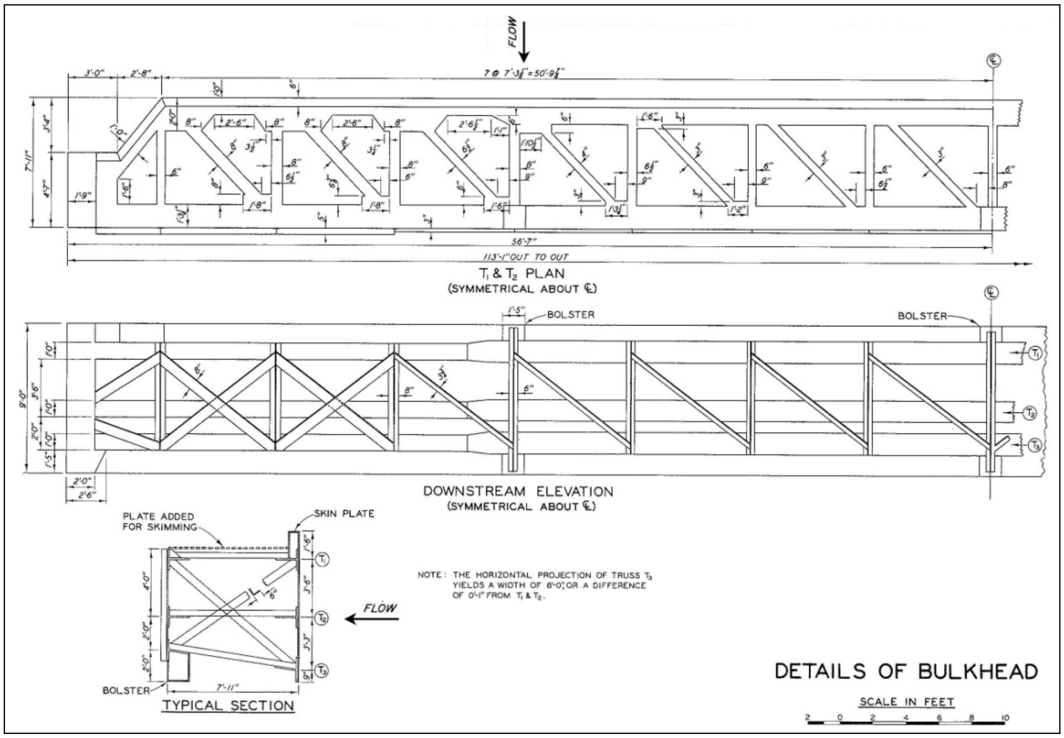

Figure 5. Bulkhead for New Cumberland Lock.

thick by 3.3 ft high. The original rectangular shape had uplift forces greater than the weight of the gate and strong vibrations were experienced during most of the gate travel. The underside of the gate was modified to a beveled shape. A schematic of the beveled gate, handling beam, and original and modified seal designs is provided in Figure 6. The modified seal was used in the prototype. The weight and shape of the handling beam gave the extra load needed to lower the gates and provided more stable operating conditions. Prototype tests showed good agreement between forces measured in the model and those measured in the field except for one of the 128 gate deployments. While deploying this one gate, the gantry crane shook violently during the last 1.0 to 1.1 ft of travel. The prototype conditions at which the shuddering occurred were extensively retested in the physical model, but the model did not reproduce the unstable conditions. The retesting did show that the modified seal performed better than the original seal design with regard to stability. The authors comment that “Nevertheless, what superficially might appear to the structural designer to be very minor changes in design must be carefully considered and studied in the hydraulic model if such changes affect parts that come into contact with flowing water.”

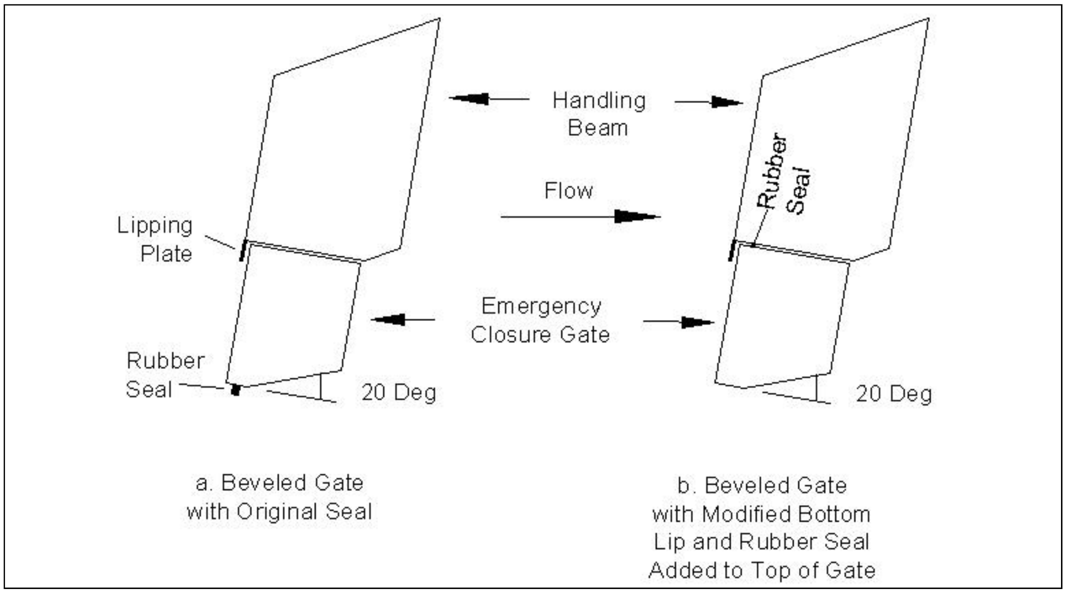

Figure 6. Gate and seal designs evaluated by Coxon et al. (1973).

The lip shape used by Coxon et al. (1973) raises the question of the bottom configuration in gate design. The USACE criteria for vertical gate bottom shape design evolved during a study of the Ft. Randall Dam, Missouri River (U.S. Army Engineer Waterways Experiment Station 1959). A physical model study was conducted after the prototype gate experienced vibration problems. The original design had a flat bottom. Experiments led to an extension on the downstream end. This reduced the vibration tendency, but additional design modifications led to a bottom shape that had a 45-degree lip (flow contracting). No vibration was found with the 45-degree gate lip. Also, the downpull or reduction of pressure on the bottom of the gate was much less for the sloping gate bottom than for the flat bottom. Therefore, the 45-degree gate lip has become standard on USACE gates because downpull forces are reduced and there is less of a tendency to vibrate (Campbell 1961).

USACE hydraulic design criteria and guidance for vertical-lift gates are given in EM 1110-2-1602 (Headquarters, USACE 1980). EM 1110-2-1603 (Headquarters, USACE 1990) discusses the bottom shape of a vertical-lift gate. It reiterates that the bottom shape of the gate has a “substantial influence” on the hoist load. The jet flow under a gate may cause oscillations (vibrations). Both the hoist load and oscillation potential are dependent on the shape of the gate’s bottom. Reference is made to the Bonneville Spillway vertical-lift gate hydraulic model study (Edmister and Smith 1975), wherein

vibration problems were eliminated by a change in the gate bottom geometry.

3.4 Barkley Dam model tests

Hite and Pickering (1983) tested a 1:15-scale model of the Barkley Dam spillway emergency bulkheads, which were designed for flow to pass both over and under each during deployment. The dimensions and shape of the gate are shown in Figure 7. The bulkheads are used to close the 55-ft-wide spillway bays. The model tests showed that the gates were stable for a wide range of conditions. Unstable loads occurred only with infrequently high tailwater which would be present when most gates were open. The designers concluded that any emergency closure at Barkley Dam could wait until the tailwater dropped into a stable range without posing a significant risk to the project.

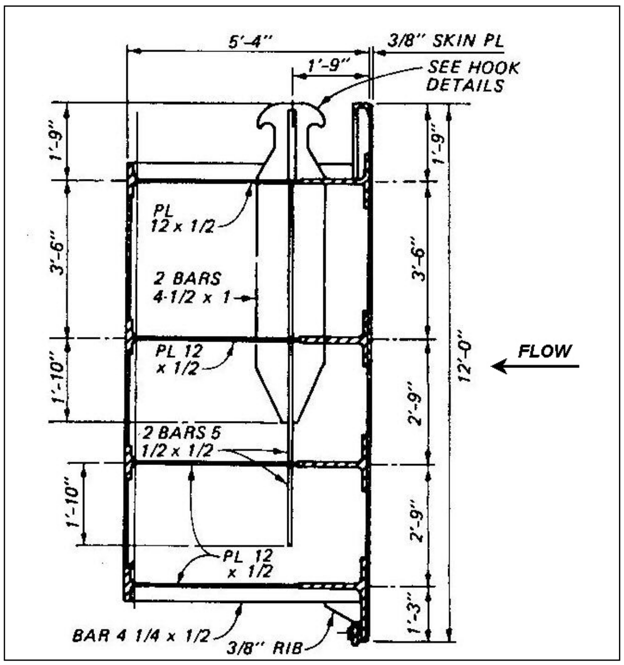

Figure 7. Details of Barkley Dam spillway emergency closure gates.

3.5 Sault Ste. Marie Canal Lock

Holder (1998) completed a 1:36-scale physical model study of emergency closure gates proposed for the Sault Ste. Marie Canal Lock. The proposed design had individual gates placed one at a time while water flowed both over and under. Figure 8 shows the various gate designs tested. All designs had a solid plate on the upstream side of the 17.4-m (57.1-ft) -long gates.

Designs with a solid plate on the bottom of the gate had high downpull forces unless a lip with 45-degree angle was added. The downpull was reduced significantly with the open truss gate design, but the gate still had problems seating as well as problems with the seated gate as the next gate was lowered into place. These problems were solved with the addition of an open truss at the top of the gate. Several tests were conducted on the configuration and position of the follower (also called lifting or handling beam), which is the device used to hold the gate during gate lowering and raising.

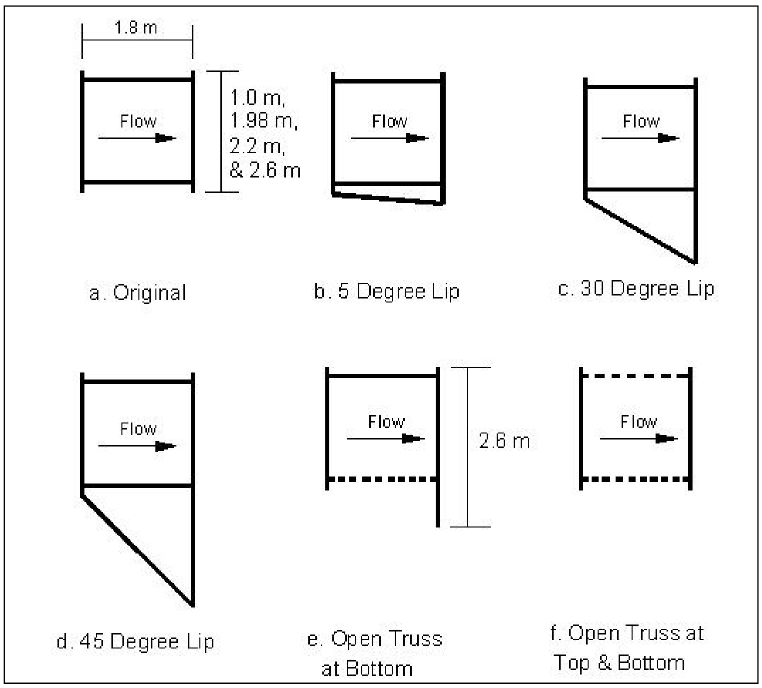

Figure 8. Designs tested by Holder (1998).

4 Emergency closure gates lowered as a single unit

4.1 Belleville and other navigation projects on the Ohio River

Belleville Locks and Dam uses stackable bulkheads to close the spillway gate bays and the lock chamber, both of which are 110 ft wide. Most of the modern era tainter-gate structures on the Ohio River have the stackable bulkhead emergency closure system similar to that used at Belleville Locks and Dam. USACE Huntington (1962) describes characteristics of the stackable Belleville bulkheads as follows:

- Each section is 11.33 ft high and can be used in the lock or spillway bay.
- They are capable of closing under maximum head of normal upper pool and minimum tailwater, which is a 22-ft difference at Belleville.
- A total of three sections are required to close one bay of the spillway or the lock.
- It requires 3.5 hours to deploy. The Belleville pool will only drop about 0.5 ft during the 3.5 hour deployment.
- Sections will be "dogged" (held in place) in the bulkhead slot by supports resting on the piers while another unit is placed on top of, and connected to, the dogged unit. This is repeated until the desired number of units are stacked and connected together. The process results in essentially a vertical-lift gate designed to close under flowing water conditions.
- Bulkhead sections are stored under the crane bridge in the tainter gate bays above maximum high water. Bulkhead sections will be raised, transported, and lowered into position by the traveling bulkhead crane.
- Sections will be transported individually to the location of closure.
- Division review commented that "The District's proposal to latch three bulkhead sections together and lower them as a unit, results in a slight increase in required hoist capacity, which is more than offset by the elimination of possible difficulties that can be encountered in latching sections underwater." Division comments also discuss "separate model studies of the truss and box girder type bulkheads indicate a more predictable hydraulic stability for the truss type bulkhead."

Figures 9-11 show pictures of the Belleville stackable emergency gates. In 2005, the vertical stackable gates were tested in the lock as part of the periodic inspection (USACE, Huntington 2005). Mr. Steve Hann of the Huntington District explained that the stacked design was tested under full flow conditions and that the test took about one-half day to complete. According to Mr. Hann, of the Huntington District's six Locks and Dams on the Ohio River, only Belleville uses stacked bulkheads in the lock. Each of the other locks use the submersible two-leaf gate discussed later in this report.

4.2 Dam 4 Monongahela River

USACE Pittsburgh (1963) describes the emergency closure gates for the spillway bays on Dam 4 Monongahela River. Each of the two non-overflow bulkhead sections are 10.25 ft high with open truss design and skin plate on the upstream side (Figure 12). The 2 sections are transported then lifted and lowered by a traveling bulkhead hoist equipped with a lifting beam. Individual sections are stacked and latched together before lowering

Figure 9. Ohio River stackable bulkheads stored above tainter gates. View looking downstream showing skin plate on upstream side of bulkhead.

Figure 10. Ohio River stackable bulkheads showing open truss on top side of gate. Some of the emergency closure gates have a solid plate on top for overflow.

Figure 11. Ohio River stackable bulkheads. View showing open truss design of bottom and downstream face. Also shows lip at bottom of upstream face.

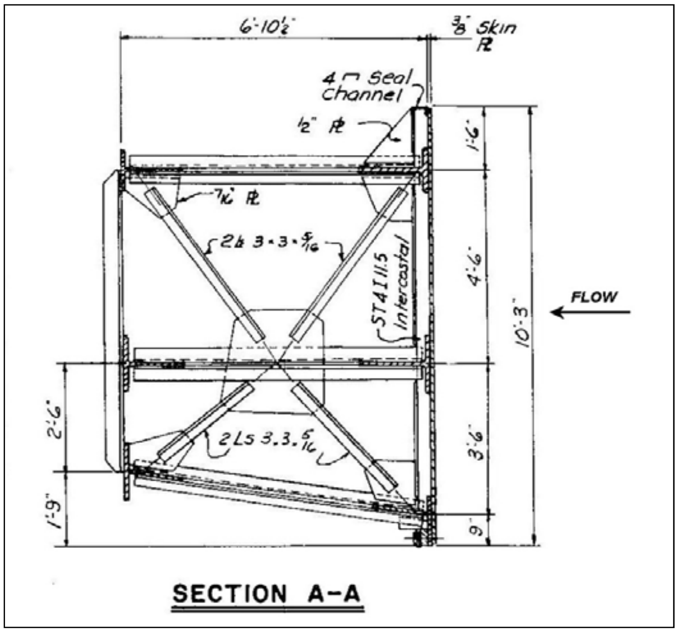

Figure 12. Emergency closure gate at Dam 4, Monongahela River.

or lifting as a composite assembly. Lowering is accomplished under open river conditions, whereas lifting is done under balanced pool conditions. The bulkheads are designed to be lowered into flow having 16.6 ft of head.

4.3 Hiram Chittenden Locks emergency closure gates

A 1:50-scale model was used to evaluate the proposed emergency closure gates for the 80-ft-wide lock at the Hiram M. Chittenden Locks on the Lake Washington Ship Canal (U.S. Army Engineer Bonneville Hydraulics Laboratory 1983). The proposed closure system used the stacked bulkhead plan where all gates are stacked and attached to each other and then lowered, resulting in flow only going under the gate. The study also looked at using the lock for additional discharge capacity and using the emergency gates as a regulating gate. The bulkhead system consisted of seven gates. The lower bulkhead section was an open truss design with a skin plate on the upstream side (Figure 13). Downpull forces in excess of the gate's weight were as large as 20 kips for all tailwaters and all opening heights between the bottom of the lowest bulkhead and the sill. The bulkheads did not vibrate during lowering or when suspended in the flow. No uplift forces were measured. The bulkhead closure system also performed well as a regulating gate. A limited number of tests were conducted with a single bulkhead. The single bulkhead would jam in the slots before seating. Downpull forces with a 10-ft head were as high as 51 kips and uplift forces were as large as 26 kips.

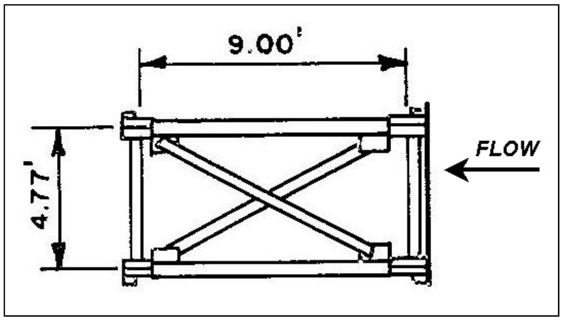

Figure 13. Bulkhead section for Hiram Chittenden Lock emergency closure.

4.4 Lake Buchanan Dam model study

Freckleton et al. (2011) studied emergency closure gates for the Lake Buchanan Dam at scales of 1:16.5 and 1:20. The method of deployment was the same as described above for Belleville Locks and Dam, Dam 4 on the Monongahela River, and Hiram Chittenden Locks. The individual sections were stacked and connected together then lowered as one unit such that only underflow occurs. Freckleton et al. (2011) provide loading diagrams for different rates of lowering with the downstream tainter gate fully open, 2/3 open, and 1/3 open. Tests with individual gate deployment with flow both over and under were unsuccessful. Individual gates jammed in the slots and uplift forces were generated when flow started going over the top.

5 Emergency closure gates raised into flowing water from the lock sill

5.1 Greenup Locks and Dam model study

Melsheimer (1959) conducted a 1:25-scale model of the emergency closure gate proposed for Greenup Locks and Dam to evaluate stability of flow during the gate raising. The emergency closure gate consisted of a 110-ft-wide two-leaf gate upstream of the upper miter gate, which was raised from the sill such that flow only passed over the gate. The gate design had a lower, upstream gate that was stationary and an upper downstream gate that seals against the lower gate and is raised through the flow. Various designs were tested and some experienced violent bouncing during certain tailwater conditions. The recommended design shown in Figure 14 was stable for all conditions and did not require nappe aeration.

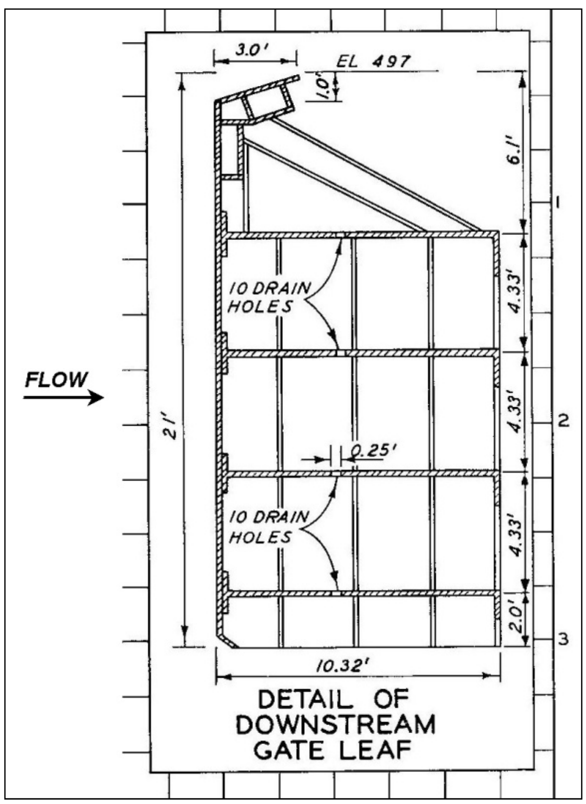

Figure 14. Recommended design of vertical-lift gate at Greenup. Gate is raised from lock gate sill.

5.2 McAlpine Locks and Dam prototype tests

Prototype tests of the emergency closure gates at McAlpine Locks and Dam were performed during August-October 1961. Flow conditions during the gate raising are shown in Figures 15-17. The crest of the McAlpine gate was based on and almost identical to the Greenup crest developed in the model study discussed previously. These submersible two-leaf gate crest shapes were built at Greenup and Markland and in 1964 were proposed for Cannelton Locks and Dam. A separate model study was conducted of the McAlpine emergency closure gate. The prototype tests showed stable gate operation under severe flow conditions. Gate vibration was low and good agreement was found between prototype and model loads.

5.3 Barkley Lock and Dam model tests

Murphy and Cummins (1965) conducted a 1:25-scale model study of the Barkley Dam emergency closure gate used at the 110-ft-wide lock. The Barkley Lock uses a single-leaf submersible type gate that rises above the upstream sill. Various designs were tested and some had large uplift forces approaching the dry weight of the gate. The recommended design, shown in Figure 18, was stable. Flow over the 45 degree lip is from left to right.

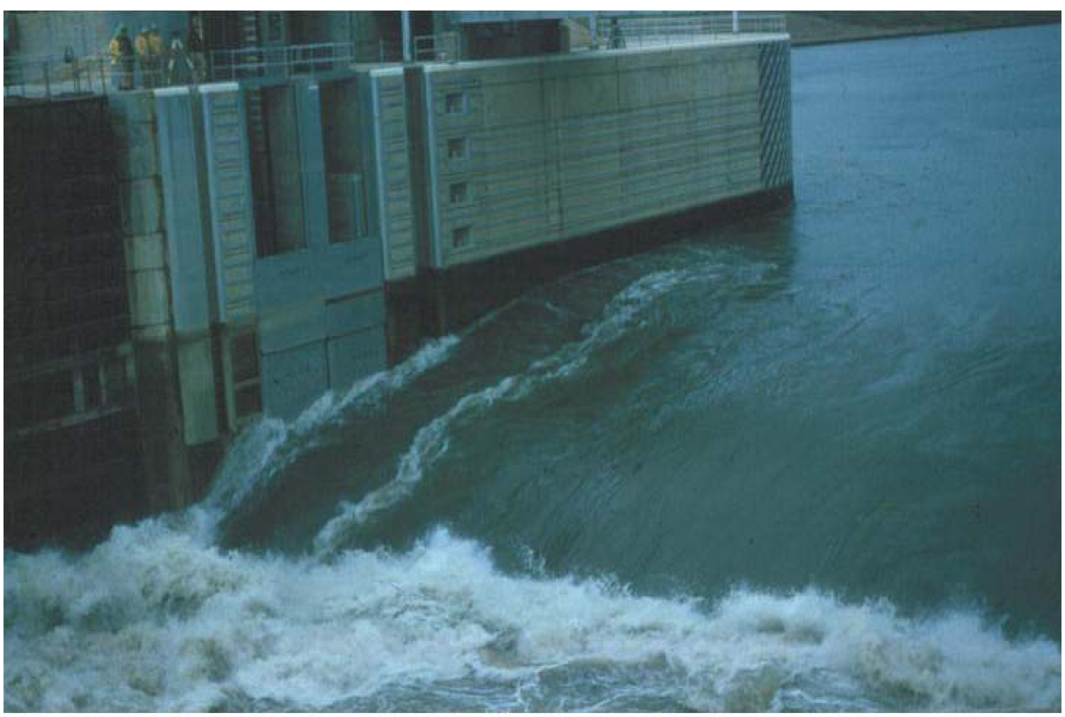

Figure 15. McAlpine Lock emergency closure tests. Flow conditions before gate is raised.

Figure 16. McAlpine Lock emergency closure tests. Gate approaching upper pool elevation.

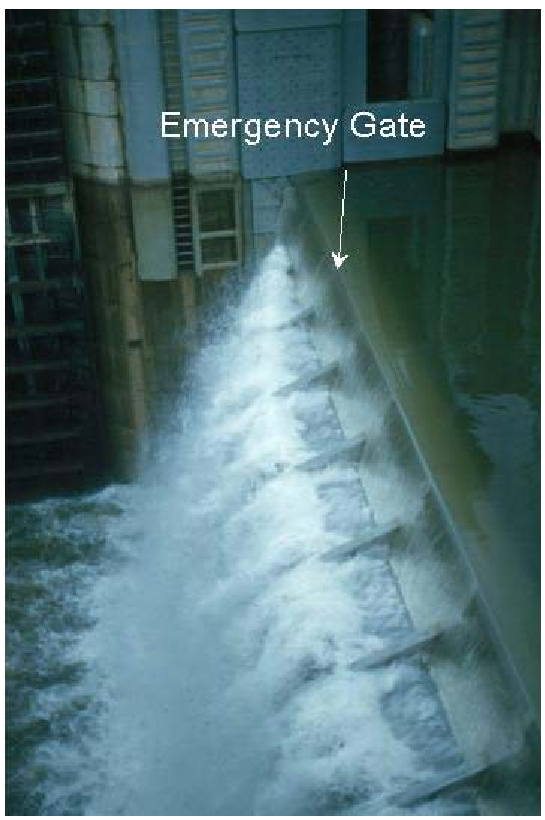

Figure 17. McAlpine Lock emergency closure tests. Gate near upper pool elevation.

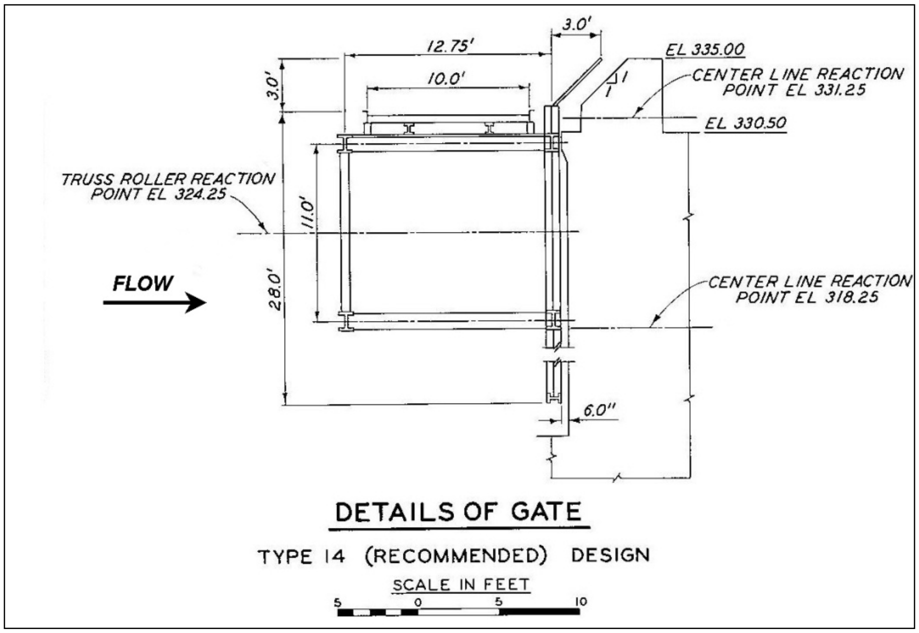

Figure 18. Barkley Lock emergency closure gate. Gate rises from the bottom. Note the gate is shown in the down position adjacent to the upstream miter gate sill.

6 Alternate means of emergency closure

Navigation dams are susceptible to accidental collision of barges into the spillway gates. Several instances of barges becoming lodged at the bulkhead location have precluded the installation of emergency closure gates (Headquarters, USACE 1995). The USACE has recently evaluated use of water-filled geotextile tubes to close levee breaches (Resio and Boc 2011). These tubes are made of waterproof material having extremely high tensile strength that could be configured into a variety of shapes other than cylindrical. Closure devices could be made of material similar to that used for inflatable gates. These gates are synthetic fiber coated with a nonpermeable material. Inflatable gates have been in use since the 1950's (Zipparro and Hasen 1993). Today's materials are resistant to ultraviolet light attack and abrasion although they are still susceptible to penetration.

A textile closure device is flexible because it is not fully inflated and can likely deform to seal against a barge wrapped around a pier. Since the width of a spillway bay or lock chamber is known, tubes could be custom fabricated and centrally located to serve numerous locks and dams having common opening widths. A small program of research in a physical hydraulic model would be needed to determine the proper size and shape of the textile closure device as well as the required amount of air and water to inflate the device. Positioning requirements upstream of the dam would also be determined in the physical model.

7 Summary and conclusions

This report summarizes guidance, past studies, and full-scale experience with emergency closure gates as follows:

- Emergency closure gates at locks are either lowered from above or raised from the sill into the flowing water.
- Emergency closure of spillway bays involves lowering gates into flowing water.
- The preferred method of closure at both locks and spillways is lowering the gate as a single unit with only underflow. Instability and seating problems can occur when individual gates are lowered into the water while flow passes both over and under.
- There is no particular size or condition that determines whether a single gate or a series of individual gates should be used. For the square or rectangular cross section bulkheads used at large span locks and spillway gates, testing and experience by Eschler (1958), Melsheimer and Murphy (1961), Hite and Pickering (1983), and Holder (1998) show that deployment of a series of individual gates is feasible. However, these same studies show that at higher heads and flow rates, the series of individual gates is not stable.
- Whether using a single gate or a series of individual gates, the upper and lower surfaces of the large span bulkhead gates using a square or rectangular cross section should be an open truss design.
- Changes in gate components that come into contact with the flow, may appear to be minor to the structural designer however they “must be carefully considered and studied in the hydraulic model” Coxon et al. (1973).
- Most of the modern era tainter gate structures on the Ohio River, dating to the 1960s, have used stackable square-section bulkheads for emergency closure. These bulkheads are stacked, connected together, and then lowered as a single unit with flow under the gate. The system is field tested during periodic inspections.
- The USACE criteria for vertical-lift gate require that the bottom have a 45-degree gate lip (downward from the upstream edge). The 45-degree lip is standard on USACE gates because downpull forces are reduced and there is less of a tendency to vibrate (Headquarters, USACE 1990).

- An alternate method of emergency gate closure is proposed using geotextile tubes similar to those recently developed by the USACE for levee breaches.

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14. ABSTRACT
This report presents a review of emergency closure devices for locks and dams. It focuses on the hydraulic aspects of emergency closure using either a gate placed as a single unit or one placed as a series of individual sections. This report also examines guidance, past field experience, and model investigations of placing emergency closure gates in flowing water. A concept for an alternative means to stop water flowing through an open spillway bay is also proposed.

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